

# PERFORMANCE AND EMISSION CHARACTERISTICS OF CASHEW NUT SHELL PYROLYSED OIL – WASTE COOKING OIL WITH DIESEL FUEL IN A FOUR STROKE DI DIESEL ENGINE

VENKATESAN KUPPUSAMY<sup>1</sup> & SATHYARAJ SANKERLAL<sup>2</sup>

<sup>1</sup>Associate Professor Department of Mechanical Engineering, Koneru lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

<sup>2</sup>Assistant Professor Department of Mechanical Engineering, Konerulakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

## ABSTRACT

India is considered as the fourth largest energy consumer in the world after the United States, China, and Russia. India's energy consumption is increasing in a relatively faster rate in the recent years, due to population growth and economic development of the country. This work focuses on the performance of waste cooking oil and Cashew nut shell pyrolysis oil blend with diesel fuel, used in a four stroke diesel engine. The pyrolysis process was used to extract the cashew nut shell pyro oil from the Cashew nut shell bio mass. The Cashew nut shell biomass was used at the reaction temperature of 800°C to obtain cashew shell pyro oil from fast pyrolysis process. The Cashew shell pyro oil and waste cooking oil properties were studied. The blending of pyrolysis oil and waste cooking oil is done by mixing of diesel fuel by volume called as CPO5WC5D90 (5%CPO+5%WC+90%D), CPO10WC5D85 (10%CPO+5%WC+85%D) and CPO15WC5D80 (15% CPO + 5%WC + 80% D). Characteristics of a fuel for Diesel fuel, and blending of CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 were analyzed. All the blended fuels were tested in a 1500 rpm single cylinder four stroke diesel engine for their performance as blended fuel. Engine test results showed that the performance for all CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 related to diesel fuel. At the

Maximum power output the brake thermal efficiency was found to be 29.0% for CPO5WC5D90 and where as it was 30.5% with diesel fuel. All blended fuel has drastic reduction for the smoke and NO<sub>x</sub> emissions. The HC and CO emission slightly more for CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 as fuel compared to diesel fuel at all power outputs.

**KEYWORDS:** Cashew nut Pyro oil, Pyrolysis Oil, Waste Cooking Oil, Diesel Engine, Engine Performance & Exhaust Emission

**Received:** Nov 18, 2017; **Accepted:** Dec 08, 2017; **Published:** Dec 30, 2017; **Paper Id.:** IJMPERDFEB201821

## INTRODUCTION

Environment from exhaust emissions and global warming have generated intense interest in developing alternative non-petroleum fuels for engines. Large quantities of waste cooking oil (WC) are available throughout the world. Estimates of the amount of WC in the US range from 1.2 billion to 3 billion gallons a year [1]. Cooking oil is normally from vegetable oil and is used for cooking or food frying purposes. These organic seed oil such as palm, coconut, soybean, rapeseed, sunflower and their ester are considered as viable bio-fuels for diesel engines. They are renewable, nontoxic, and biodegradable and their properties are comparable with diesel fuel. Diesel engines have been designed to run over a wide range of heavy to light hydrocarbon fuels. Heavier grades of

petroleum fuel known as the light oil are suitable for slow speed engines whereas these fuels are unsuitable for high speed diesel engines [2]. Bio oil fuels are renewable energy liquid fuels coming from biological raw material and have recognized to be good substitutes for oil in the automobile sector. Biodiesel can be blended in any ratio with petroleum diesel fuel. The use of bio fuel in conventional diesel engines results in substantial reduction of HC, CO and particulate matters. Bio fuel is considered clean fuel, since it has almost no sulphur contents, and has above 15% built in oxygen, which helps it to burn completely its greater amount of Cetane number to improves the combustion even when blended in the petroleum diesel [3], [4]. In observation of its combustion characteristics, bio fuel can be used as fuel for diesel engines (as either, B5 –a blend of 5% bio-fuel with diesel or B20 or B100). Now a days, United states of America uses B20 and B100 biodiesel and France country uses B5 as mandatory [5]. It was found that the mixture of 5%, 10% and 15% by volume of Cashew shell pyro oil, respectively with 90%, 85% and 80% by volume of diesel, and 5% by volume of WC were found stable and homogeneous for a long period of time (two month). Beyond 15%, separation was noticed and hence, the quantity of Cashew shell pyro oil and waste cooking oil used was limited up to 15%. Experiments were performed on a single cylinder diesel engine using the CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 prepared with the volume of Cashew shell pyro oil and waste cooking oil to study the performance behavior of the engine. Results were compared with conventional diesel fuel and analyzed.

## **PYROLYSIS SET UP AND EXPERIMENTS CONDUCTED**

### **Working Operation of Pyrolysis Set**

The pyrolysis setup consists of a square shaped thermal reactor made of copper material with a wall thickness of 8 mm. The reactor has an inlet and outlet for supplying nitrogen gas ( $1.0 \text{ kg/cm}^2$ ) at inlet and transferring volatile gases at the outlet. The outlet of the reactor was directly connected with the help of an alloy gasket to the condenser using an aluminum tube which can withstand temperatures. The outlet was connected to aluminium condenser used for the condense process of a counter flow type and is connected to the gas liquid separator unit. The flow of water was directed against the direction of pyro gas flow in the condenser part. The condensate was allowed to drip into the gas liquid separator. The non-condensable gases were allowed to pass through the exhaust tube to connect gas burner. An auto controller chromel-alumel thermocouple connected with a digital temperature indicator was used to measure the temperature inside the reactor. A nitrogen cylinder was used to supply the nitrogen gas into the reactor to purge the oxygen present in the reactor to reduce combustion inside the reactor. Initially, the cashew shell were cut into small size and dried in the sunlight. The dried cashew net shell was fed into the reactor through feeder of the reactor for pyrolysis. The pyrolysis reaction was carried out at the temperature of  $800^\circ\text{C}$ . The vapor coming out from the pyrolysis reactor was allowed to pass through the aluminum condenser, which acts as counter flow heat exchanger and condensed by circulating cooling water. The Cashew shell pyro oil was then collected in a steel container. The extracted pyro oil was then purified and analyzed for its physical and chemical properties to use as pyro fuel.

### **Preparation of Pyro Oil Blends**

Pyro oil can be prepared by mixing the waste cooking oil (bio diesel) with cashew shell pyro oil and diesel fuel. For preparing them CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 (5%CPO+5%WC+90%D), (10%CPO+5%WC+85%D) and (15% CPO + 5%WC + 80% D) were taken in a container. The mixture was stirred vigorously, until a homogenous mixture was formed. The stirrer speed was maintained as 800 rpm. Stable oil preparation may be obtained by stirring the mixture for 20 to 25 minutes, and the stability of the homogeneous mixture was found as

stable for three month. The blending of oil was mixed with the help of a mechanical stirrer, and it is founded that up to 15% of Cashew shell pyro oil blends easily with waste cooking oil and diesel fuels, without any separation for long time. CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 blends of cashew shell pyro oil and waste cooking oil have low viscosity, density, flash point, fire point, and calorific value compared to diesel fuel. All the pyro oil properties of blends are closer to that of diesel fuel.



**Figure 1: Photographic View of Preparation of Pyro Oil Blends**

**Table 1: Properties of Different Pyro Fuel Blends**

Properties	Neat Diesel	Neat	WC	CPO5WC5D	CPO10WC5D8	CPO15WC5D
Density (kg/m) <sup>3</sup>	840	924	920	865	885	895
Flash Point (C)	52	62	65	58	62	66
Fire Point (C)	56	68	108	62	67	69
Calorific Value(MJ/k	43.50	45.0	41.83	42.36	41.85	40.26
Viscosity	3.41	7.3	14.5	4.3	5.3	5.9
Water Content (%)	0	7.5	0	1.0	2.6	3.2
PH Value	4.6	4.7	5.2	4.9	5.6	5.8

### Engine Setup

A mono cylinder (KIRLOSKAR), 4-Stroke, water-cooled, direct injection diesel engine develops a power output of 4.4 kW at 1500 rpm. Water cooled eddy current dynamometer was used for loading the engine. The test engine setup can be seen in figure 2. The fuel flow rate was measured on the volumetric basis using a burette and stop watch. An AVL444 exhaust gas analyzer was used for measuring HC, CO and NO in the exhaust. Black carbon smoke levels were measured by using a standard AVL smoke meter. Tests were accompanied for five different loads such as 20%, 40%, 60%, 80% and 100% of the maximum power output with the fixed engine speed of 1500 rpm. All the tests were carried out with the injection timing of 27° before TDC for all the tested fuels. All the tests were repeated three times to get an optimum value. Initially, the diesel engine was run on diesel fuel. Then, the engine was run on CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 fuels blends.



**Figure 2: Photographic View of Experimental Engine Set-Up**

## RESULTS AND DISCUSSIONS

### Performance Characteristics

The experiments were done at different load 20%, 40%, 60%, 80% and 100% Static injection timing  $27^\circ$  BTDC at the rated injection opening pressure  $180 \text{ kg/cm}^2$ . The specific fuel consumption (SFC) and the brake thermal efficiency (BTE) can be calculated by the engine speed, torque and mass consumption rate of the fuel. Figure. 3 and 4 show the SFC and the BTE variations under different brake power for 1500 rpm. The SFC of the blended pyro oil is slightly increased than that of diesel fuel. This is due to the effect of viscosity and density and mixture formation of cashew shell pyro oil and waste cooking oil blends of pyro oil. The increase in blend percentage of pyro oil the calorific value decreases. Hence, CPO5WC5D90 blend gives less SFC compare to CPO10WC5D85 and CPO15WC5D80. Hence, because of Specific fuel consumption of the higher percentage of pyrolysis, blends increases compared to that of diesel fuel.

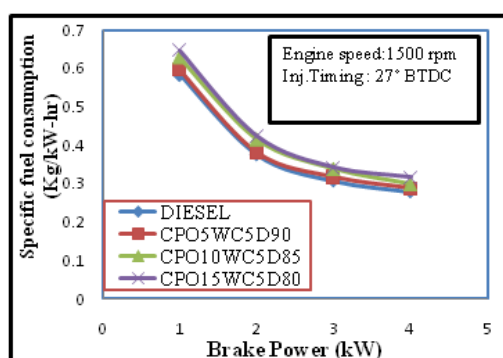


Figure 3: Comparison of Specific Fuel Consumption with Brake Power

In all the cases, BTE has the tendency to increase with increase in brake power. The BTE of all blends of pyro oil is lower than that of diesel fuel. This is due to high viscosity and density of CPO blends. CPO5WC5D90 blend gives the slightly higher BTE compared to other fuels namely, CPO10WC5D85 and CPO15WC5D80. Hence, because of an account of the secondary atomization of fuel resulted in improved mixture formation. At the maximum power output, the brake thermal efficiency was found as 29.0% respectively, with CPO5WC5D90 and whereas, it was 30.5% with BD. It can be observed that the exhaust gas temperature generally increases with increase in blend concentration and load. The exhaust gas temperature as shown in Figure.4 is higher for all the blends of pyro oil as compared to BD operation at all power outputs. The exhaust gas temperature increases with blending. This increase in the exhaust gas temperature may be due to the high viscosity and density of the oil than diesel [6]. The CPO5WC5D90CPO10WC5D85 and CPO15WC5D80 blend increase in exhaust gas temperature with these fuels, due to the combustion occurring slightly more in the diffusion stage, and resulted in late burning to be more, as a result of slow burning nature of pyro oils resulting in higher exhaust temperature.

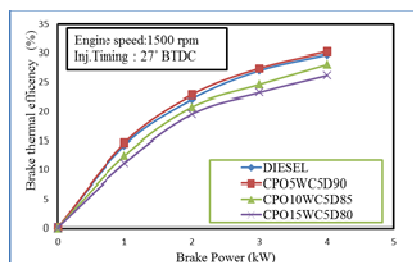


Figure 4: Comparison of Brake Thermal Efficiency with Brake Power

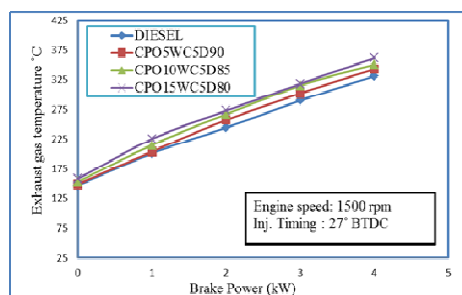


Figure 5: Comparison of Exhaust Gas Temperature with Brake Power

### Emission Characteristics

The smoke emissions resulted from burning of BD and the pyro oil blends are indicated in Figure. 6, Smoke level increased with increase in engine power. It is seen that the smoke emission was found as lower for all the pyro oil blends at all power outputs, as compared to diesel fuel operation. The lowest smoke emission was found with CPO5WC5D90 as 38 ppm, followed by CPO10WC5D85 as 36 ppm and CPO15WC5D80 as 33 ppm. In diesel engines, smoke is formed as 40 ppm, because of secondary atomization occurring in the combustion process.

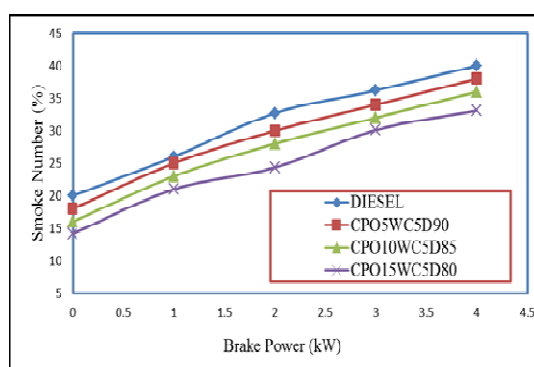
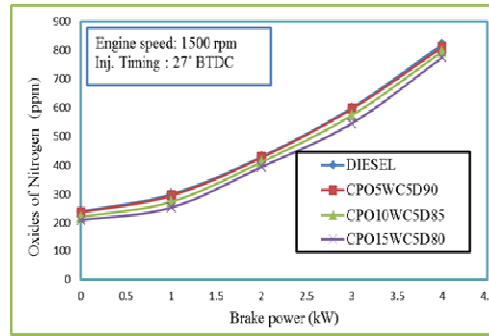


Figure 6: Comparison of Smoke Emissions with Brake Power

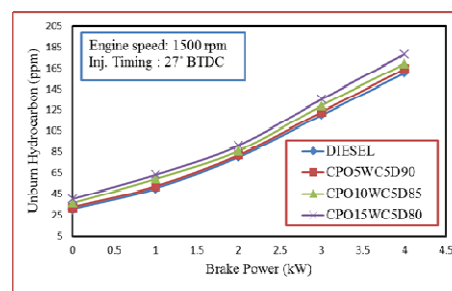
Pyro oil blends resulted in considerable reduction in NO<sub>x</sub> emissions as compared to BD, at all power outputs as shown in Figure. 7. All blends of pyro oil resulted in lowest NO<sub>x</sub> emission compared to diesel fuel. This may be, because of the presence of oxygen in fuel blends as vegetable oils that have a small amount of oxygen. It can be seen that the oxide of nitrogen emissions decreases with blend ratio. The probable reason may be, due to heat release caused by the lower heat content of pyrolysis oil by increasing the oil percentage in blending [7]. At the maximum power output of 4.4 kW the NO<sub>x</sub> emission was found as 810 ppm, 795 ppm and 774 ppm respectively, with CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80, whereas, it was 820 ppm with BD. CPO15WC5D80 shows ppm when compared with diesel fuel. The reduction in NO<sub>x</sub> emission with the pyro fuel blend is due to the lower air fuel ratio of the injected fuels and lower heating value for the given power output.



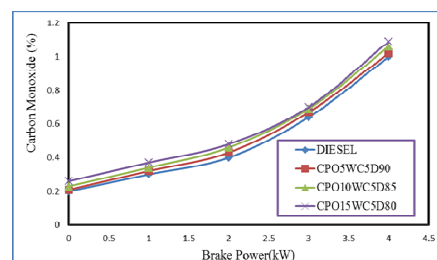
**Figure 7: Comparison of Nitrogen Oxide with Brake Power**

The variation of hydrocarbon emission with brake power for CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 is shown in the figure.8 It is seen that all the tested fuels resulted in higher hydrocarbon emissions at all operating conditions, as compared to BD operation. The probable reason for emission may be, some portion of the fuel air mixture in the combustion chamber comes into direct contact with combustion chamber wall and get quenched. Some of this quenched fuel-air mixture is forced out during the exhaust, which contributes to the high hydrocarbon emission [8]. At the maximum power output, the hydrocarbon emission was found as 164 ppm, 169 ppm, and 178 ppm for CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80, respectively. The main reason for the higher hydrocarbon emissions with the pro oil blends can be explained by the result of high latent heat of vaporization of water, presented in the fuel. It was noted as 160 ppm with diesel fuel.

Figure.9 indicates the results of carbon monoxide emissions of CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 and BD at different power outputs. All the pyro oil blends resulted in higher CO emissions, as compared to BD at all power outputs. The maximum CO emission was found as 1.02%, 1.06% and 1.09% respectively, for of CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80 at the power output of 4.4 kW. It was noted as 1.0 % with BD. The CO emission emitted from diesel engine is due to the fuel richness, which results in partial oxidization of carbon in the blended fuel.



**Figure 8: Comparison of Hydrocarbon Emission with Brake Power**



**Figure 9: Comparison of Carbon Monoxide Emissions with Brake Power**

## CONCLUSIONS

The engine does not run while using pure waste Cooking Oil and cashew shell pyro oil, its blend is due to high viscosity and density of the fuel. Cashew shell pyro oil has higher efficiency than diesel. All Blends of pyro oil with diesel blends are CPO5WC5D90, CPO10WC5D85 and CPO15WC5D80, resulted in comparable performance with slight reduction in BTE at all power outputs. CPO5WC5D90 indicated slight increase of BTE, as compared to other two blends. The significant reduction in NO<sub>x</sub> and smoke emissions were achieved with all the blends. HC and CO emission showed slight increase than diesel fuel. Use of cashew shell pyro oil and waste cooking oil blends can be used as alternative fuels, without engine modification and partial replacement of diesel by pyro oil blends with diesel.

## REFERENCES

1. M. Pugazhadviva, K. Jeyachandran, "Investigations on the Performance and Exhaust Emissions of a Diesel Engine Using Preheated Waste Frying Oil as Fuel", *Renewable Energy*, Vol.30, 2189–2202, 2005.
2. Bari S, Yu WC, Lim TH. *Performance deterioration and durability issues while running a diesel engine with crude palm oil*, *Proc. Instn Mech. Engrs, Part D, J. Automobile Engineering* 2002; 216(D1): 785-792.
3. Biodiesel, *National Biodiesel Board Report*, Jefferson City, MO 65110-4898, USA, 1999.
4. Bhattacharya TK, Chatterjee S, Mishra TN. *Studies on suitability of lower ethanol proofs for alcohol-diesel micro emulsions*, *Agricultural Mechanization in Asia, Africa, Latin America*, 34(1), 2003.
5. Shivaji, Kailash B Anwar & S. Gowreesh, *Experimental Investigation on Use of Preheated Pongamia Oil Bio-Diesel in DI Diesel Engine*, *International Journal of Automobile Engineering Research and Development (IJAuERD)*, Volume 4, Issue 6, November - December 2014, pp. 1-6
6. Stage P, Mouloungui Z, Vaitilingom G, Berge JC, *Interest of combining an additive with diesel-ethanol blends for use in diesel engines*, *Fuel*, 2001, 80, PP, 565-574.
7. Babita Singh, Dulari Hansdah & S. Murugan, *Performance and Exhaust Emissions of a Diesel Engine Using Pyrolysis Oil from Waste Frying Oil and Castor Oil Mixture*, *International conference on sustainable mobility 2010*, 1st - 3rd December 2010, Kuala Lumpur, Malaysia.
8. Manu Ravuri, D. Harsha Vardhan & V. Ajay, *Comparison of Performance of DI Diesel Engine Using Jatropha and Neem Oil*, *International Journal of Automobile Engineering Research and Development (IJAuERD)*, Volume 3, Issue 1, January - February 2013, pp. 57-62
9. Heywood, J. B, *Internal Combustion Engine Fundamentals*, 3rd Edition, McGrawHill, Inc. New York, NY, 1988.
10. Ganesan. V, *Internal Combustion Engines*, 2<sup>nd</sup> Edition, Tata McGrawHill Publishing Company Limited, New Delhi, 2003

